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SEARCH FOR GAMMA-RAY BURSTS WITH COINCIDENT BALLOON FLIGHTS

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— GODDARD SPACE FLIGHT CENTER —

GREENBELT, MARYLAND

Search for Gamma-Ray Bursts with Coincident Balloon Flights

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We report on an experiment to search for cosmic gamma-ray bursts of the type discovered by Klebesadel et al.,¹ but of smaller size and of sufficient frequency of occurrence to be detected during a one-day observation program. Two similar detectors, successfully balloon-borne from launch sites in South Dakota and Texas, achieved about 20 hours of simultaneous operation at several millibars atmospheric depth, with continuous separation of over 1500 km on 10-11 May 1975. Fluctuations of the counting rates of > 150 keV photons with temporal structures from microseconds to several minutes were compared in order to detect coincident or associated responses from the two instruments. The results of this experiment can be summarized as follows. First, no coincident gamma-ray burst events were detected. Second, the resulting integral size spectrum of small bursts, from this and from all other searches, remains a spectrum of upper limits, consistent with an extrapolation of the size spectrum of the largest known bursts, fitting a power law of index -1.5 . Third, a curious effect was found which can be described as consisting of associated, but not coincident, counting-rate increases of photons of energy > 150 keV. This phenomenon undoubtedly presents a background, event-confusion problem for any single gamma-ray burst instrument, placed either on balloons or on satellites which orbit the Earth beneath the trapped radiation.

This experiment was designed to investigate the possibility that cosmic gamma-ray bursts could be detected in the size region of

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10^{-7} to several times 10^{-6} ergs cm^{-2} , below the apparent bend in the size spectrum of Vela events as described by Strong and Klebesadel.² It has generally been assumed that the observed bend could be due to instrumental effects^{3,4,5} (because the detector thresholds do not produce a sharp cutoff in event selection, due to the widely varying temporal structures of the bursts). An intrinsic bend in the true size spectrum, however, would be of great interest. A plot of $N(>S)$, the number of events of size greater than S , as a function of event size S , would vary as $S^{-1.5}$ for an extended volume of source objects positioned essentially isotropically, but as S^{-1} for a disk-shaped source region and as $S^{-0.5}$ for a one dimensional source region. Thus, the shape of the observed size spectrum not only could indicate a galactic structure in the gamma-ray burst source pattern, but also might directly calibrate the intrinsic source strength distribution from the known galactic dimensions.

Our first experiment to search for small gamma-ray bursts was the balloon-flight of a single large detector in May, 1974. The results of this program have been published^{3,6} and are summarized by the statement that a number of candidate events were found, having sizes consistent with -1.5 index power-law extrapolation, but which could not be established as true gamma-ray bursts without confirmation from another detector.

In order to obtain a more definite signature for cosmic gamma-ray bursts, the dual balloon experiment described here was carried out in 1975. This experiment consisted of flying two similar detectors simultaneously with adequate geographical separation to avoid local cosmic-ray or magnetospherically induced coincident responses. One balloon was launched at 0145 UT on May 10 from Palestine, Texas and floated until about 0400 UT on May 11. The other balloon was launched

about 0340 UT on May 10 from Sioux Falls, South Dakota and floated until 2125 UT on May 11. The distance between the balloons was always greater than the distance between the launching stations, which is about 1400 km (see Figure 1). The total time of simultaneous float above 6.5 mb residual atmospheric pressure was about 18 hours, most of which was above 3.5 mb depth.

The detector in each instrument consisted basically of a plastic scintillator 8900 cm^2 in area x 5cm thick, viewed by two 5" PM tubes in coincidence. This two-tube requirement was an improvement over the single PM version of the 1974 flight in that tube noise was reduced, but it resulted in a higher energy detection threshold for photons. The absolute threshold was at $\approx 150 \text{ keV}$, although calibration with radioactive sources showed that the average effective threshold was nearly twice this figure. Particles were excluded by a second, anticoincidence threshold set at 2.5 MeV. The results of the 1974 flight showed that an additional, thin anticoincidence scintillator on top was unnecessary; abandoning it also resulted in greater effective sensitivity. In each instrument a time interval analyzer (TIA) was used for recording the counting rate data.⁷ The TIA measured the time interval ΔT between each pair of successive photon counts. These intervals were defined within a binary logarithmic basis, i.e., 20 to 40 nanoseconds, 40 to 80 ns, 80 to 160, etc., up to a ΔT that was much longer than the inverse of the expected average counting rate. Thus, rapid but short count-rate increases (fast bursts) can be evident in a rate vs. ΔT histogram as bumps in the region of small ΔT , well separated from the main, Poisson distribution of background gamma-ray counts. We could therefore look for temporal structures in counting rates from the 40-nanosecond region continuously

to the several hundred millisecond region with the TIA, and examine for longer structures by using the total counting rate histogram. The advantage of this system over the conventional counting rate histogram scheme is that orders of magnitude lower bit-rate telemetry can be used. The Palestine TIA had a limiting resolution of $\Delta T = 20$ nsec, with accumulation time intervals $T = 320$ msec, whereas the Sioux Falls instrument analyzed down to $\Delta T = 7.8$ microsec during intervals $T = 32$ msec. In addition, the Palestine instrument contained a rate counter recording the total number of counts in 40-msec intervals. Thus, in the event of a TIA breakdown (which did not occur), independent measurements would be possible for all count-rate fluctuations from the 40-msec to the several minute region, with absolute time coincidences between the two detectors attainable to 72 msec resolution. Coincidences of increases of shorter duration could, however, be inferred from their statistical likelihood. A problem in one of the time-code generators, designed to record the received WWV time to 1 millisecond accuracy, however, resulted in an actual accuracy of only one second. Therefore, coincidences of increases of less than 1 second duration could only be inferred from their likelihood of occurrence in coincident data samples.

The results of the data reduction showed that indeed non-Poisson counting rate excursions were detected over a variety of time bases from the microsecond region to the one-minute region. These could be due, in the individual detectors, to causes ranging from cascade showers, neutron and cosmic-ray interactions, and induced radioactivity, to magnetospheric effects, i.e., to a variety of local forms of background. A phenomenological data treatment was therefore developed, consisting of

plots of the number of fluctuations vs. size in standard deviations, vs. time base on a logarithmic scale. For each of the two instruments, a smooth, three-dimensional distribution was found to contain only one bump, other than the background distribution having a maximum near the origin. In each case this extra population consisted of very long, one half to several minute, counting rate increases of many standard deviations value. No extra population was found in the 0.1 to 20 second region where all known gamma-ray bursts occur. However, all increases of over a few standard deviations from each instrument of any time character from microseconds to minutes were compared, to search for correlated increases from the two detectors. The results were that, except for those expected on a random coincidence basis, none occurred other than the very long time base population found with the plots, as described above. (It is interesting to note that gamma-ray bursts of order of magnitude shorter character than those found with the Vela satellite system would be observed with this system, but that no population at least as numerous as known gamma-ray bursts, could be found. This is probably the only system ever used other than the Vela system "fast mode"⁸ that could have responded to such fast increases with a coincident signal.)

Time histories of the most significant counting rate increases are plotted in Figures 2a, b and c. (The sensitivities of the two instruments are not the same, but, due to a minor malfunction, the rates of Palestine instrument are somewhat less, and are switched off for 5 seconds out of each 10.) If these increases were gamma ray bursts, assuming the spectrum found typical of longer events⁹, their energy content would be around 10^{-5} ergs cm^{-2} each. However, they are clearly not coincident. The

light travel time between the two detectors is only 5 milliseconds, and yet the temporal separation is many tens of seconds. They are most likely to be associated, however, since there are only several of these events in either tabulation of single counting rate histograms within the 18 hours. Thus, the probability is negligible that each pair should fall within a few minutes separation on a random basis. One explanation of this phenomenon may lie in ionospheric or magnetospheric activity with a slowly traveling disturbance center. Artificial sources are a less likely explanation. We have checked the VLF receiving records of the Naval Observatory in Washington, D.C. Records were available for the VLF stations WLK, Jim Creek, Cal., and NBA, Balboa, Canal Zone, and for the Omega stations Trinidad and LeMoure, N.D. None of these records show any disturbance during the day of May 10 during which three of our events occurred. The responsible electron fluxes would have to be small, less than one per cm^2 , such that, if magnetospheric, they lie outside the domain of typically studied trapped radiation phenomena. Such counting rate increases are clearly a danger to any experiment seeking to measure gamma-ray bursts without confirmation. In either single balloon flight, these events could have been taken to be exceptionally long gamma-ray bursts, were it not for the lack of coincident information in the other. It must be added that one associated event took place near local midnight, so it could not be of solar origin (solar flares would also, of course, be seen as exactly coincident). Thus the need is evident for more sophisticated techniques to search for small gamma-ray bursts, a need that applies to low-orbiting Earth satellites instrumentation, as well as to balloon flights.

In Figure 3 we show the upper limits to the size spectrum of gamma-ray bursts resulting from the analysis of our data. We have included 95% upper limits on the basis that we did not see any actual events in our 1975 flights; the energies where we put our upper limits depend on the time increment used for the burst search. The left mark is the result of a separate 0.1 sec search. Since the 0.1 sec events are a fairly rare subgroup of events in the total amount of satellite data¹⁰, we tend to regard the results obtained by balloons to date as inconclusive so far as the slope of the size spectrum is concerned. We feel that this unfortunately remains true when the other balloon data, as plotted on this graph, are included. A recent note¹¹ indicates our reasons for interpreting the results of another balloon experiment search¹² as also providing an upper limit to the size spectrum. That note enumerates a number of factors which contribute to rendering a balloon-borne search for bursts less efficient than it may have been intended to be. Our conclusion from this experiment, and from various others^{13,14} is that we need an increase in sensitivity by another order of magnitude to be able to adequately detect small gamma-ray bursts. If that can be done, the next step, observing a source direction anisotropy, may be possible.

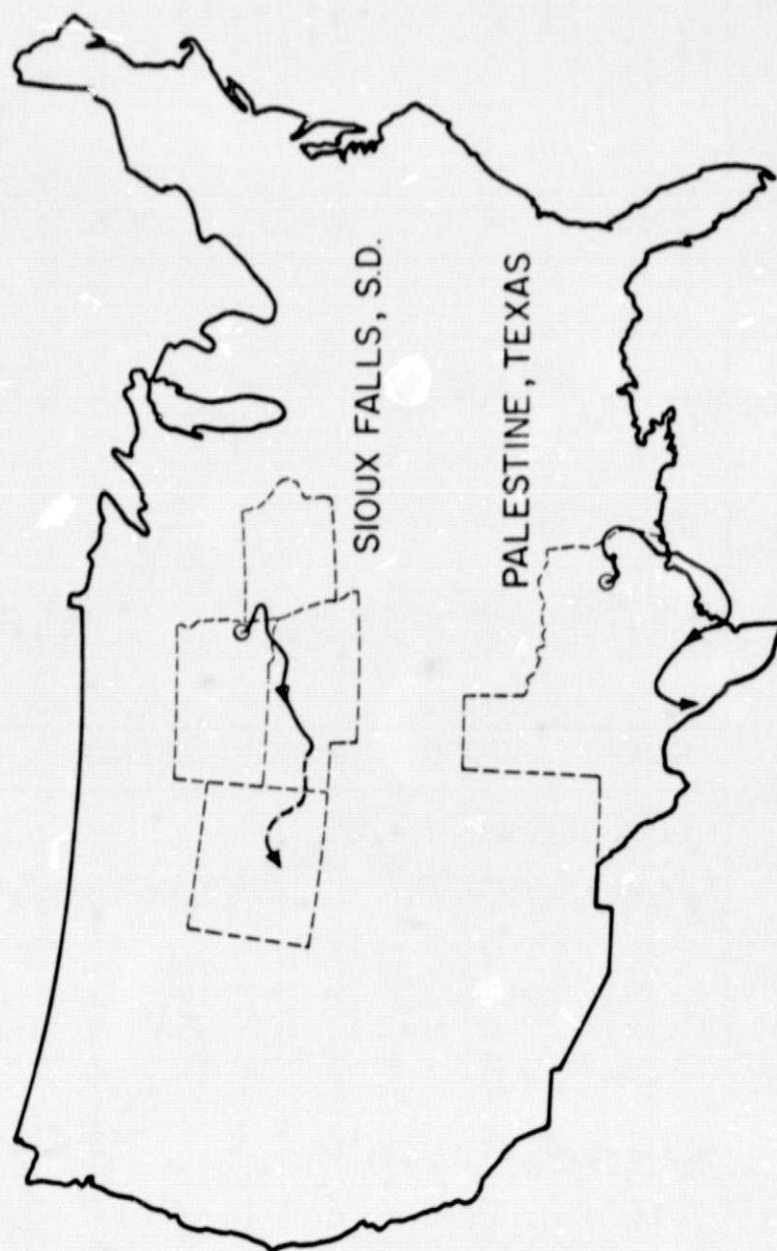
We wish to acknowledge the invaluable contributions of G. Porreca, who designed the electronics, and of H. Costlow and C. Thomas, who prepared the gondolas and assisted with the balloon flight operations.

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Figure Captions

- Fig. 1. A map of the trajectories of the two balloon borne-gamma ray detectors. This was probably the first time an astrophysical project required two high-altitude balloons in simultaneous use over a wide geographical separation.
- Fig. 2. Counting rate increases exhibited by the gamma-ray counters in three occasions. The lack of simultaneity of the events in each case disproves cosmic origin; the fact that the pairs of increases are always separated by a short time delay relative to the time between their occurrence argues for a magnetospheric origin. Such transient increases present a background problem for near-Earth gamma-ray burst detectors.
- Fig. 3. A plot of the size spectrum of known, large gamma-ray bursts and of the various upper limits to the intensity of small bursts, obtained from this and other balloon-borne searches.



MAY 10-11, 1975 DUAL BALLOON FLIGHTS

Figure 1

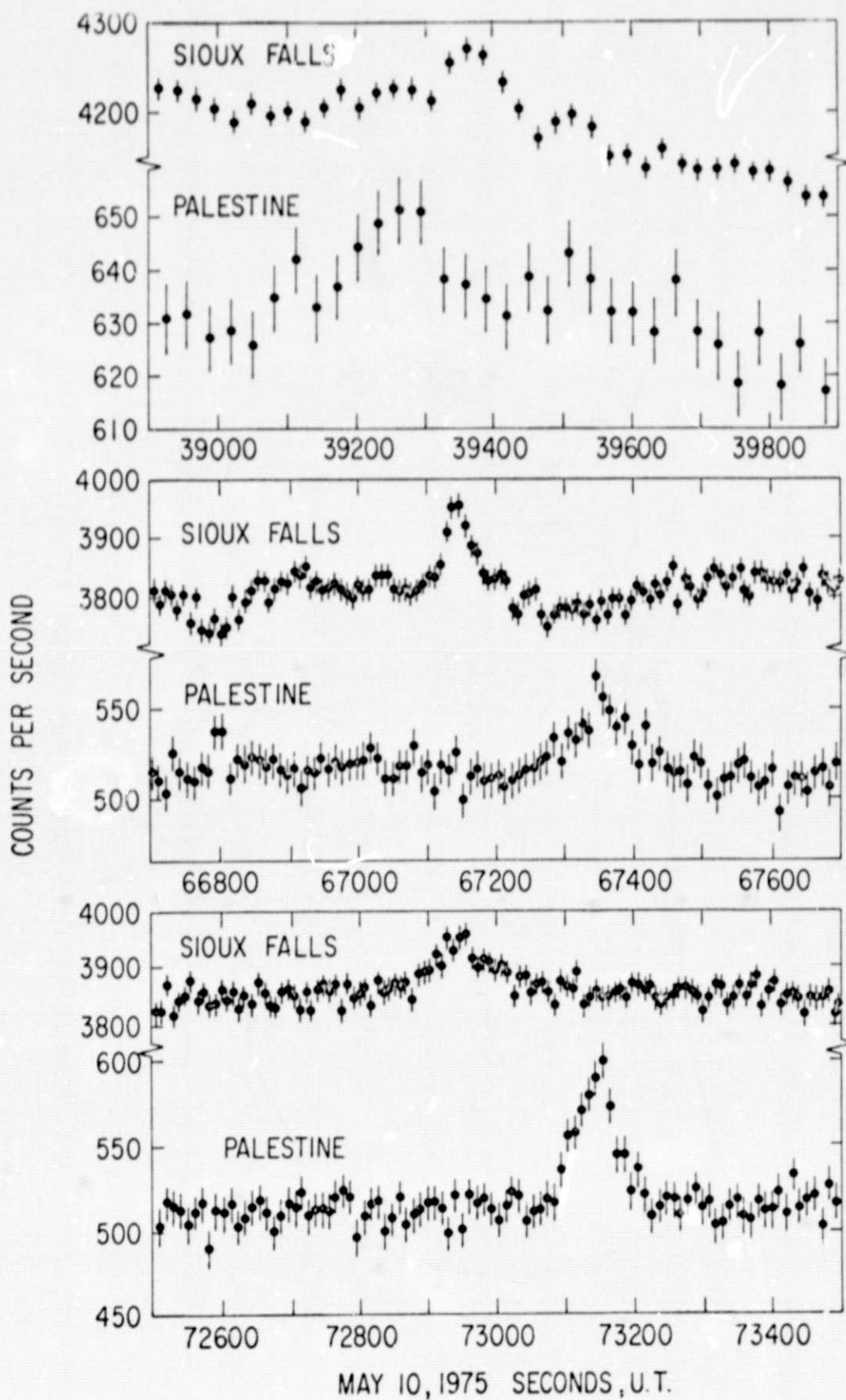


Figure 2

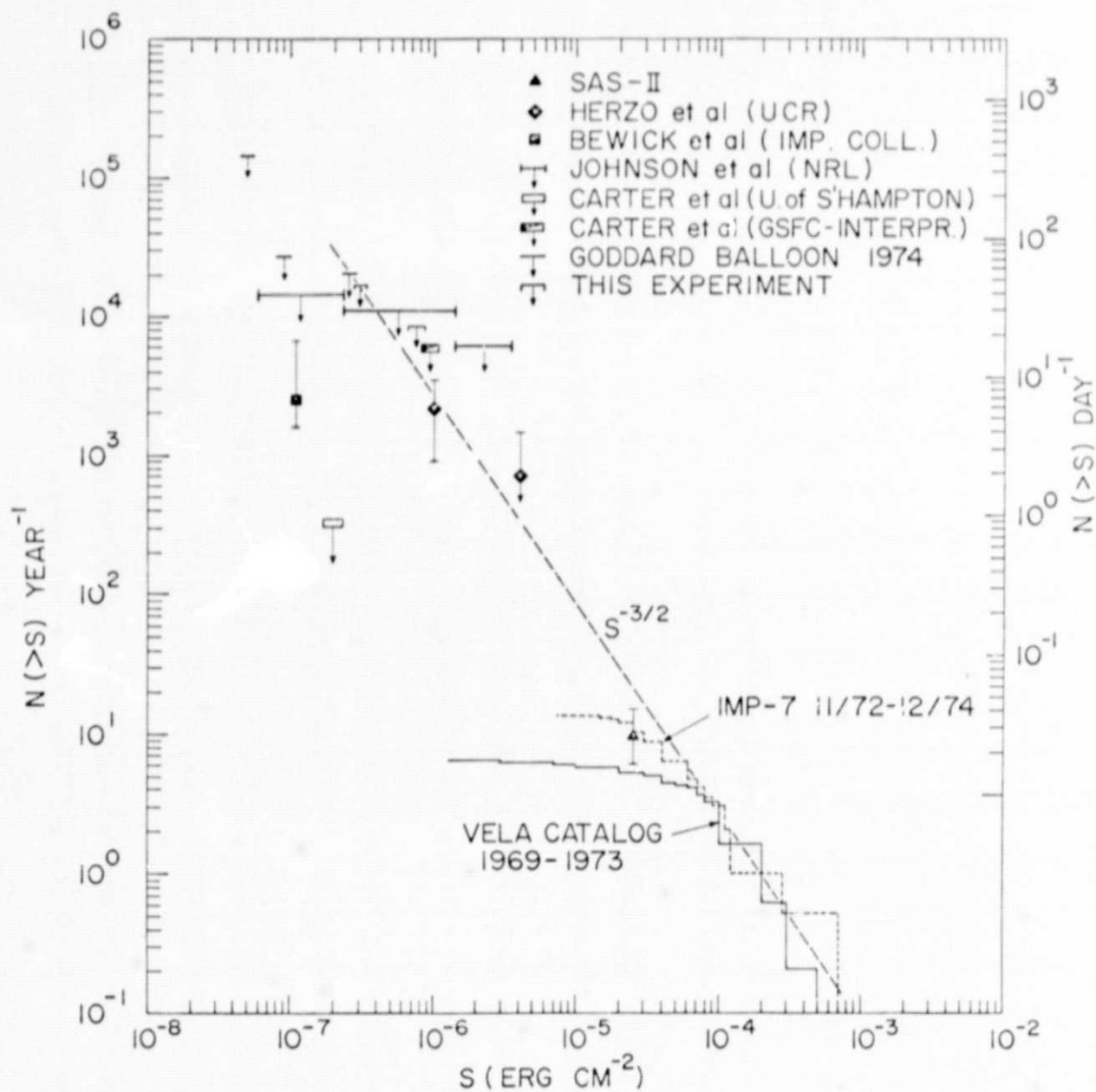


Figure 3